Nanostructured Zn-Based Electrodeposits for Cd-Replacement on High-Strength Steel Fasteners

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Technical Objective

Project Objective of SERDP Project

- Investigate the benefit of a nanostructured microstructure on the properties and performance of various Zn-Based alloy coatings
- Where possible work on simple modifications to conventional electroplating techniques with the end goal of developing an alloy that:
  - Meets or exceeds the overall performance (corrosion protection, torque-tension, hydrogen embrittlement, etc.) and life-cycle cost of existing cadmium electroplating
  - Provides a "Drop-in" replacement for Cadmium plating, capable of using existing Cd plating infrastructure
  - Does not have any environmental or worker safety issues

Develop an understanding between the microstructure (grain size, crystal structure (phase) and composition) and the properties and performance (sacrificial corrosion, lubricity, hydrogen embrittlement) of Zn-based alloy coatings on HSS → **Microstructurally Designed Cd-Replacement**

Performers

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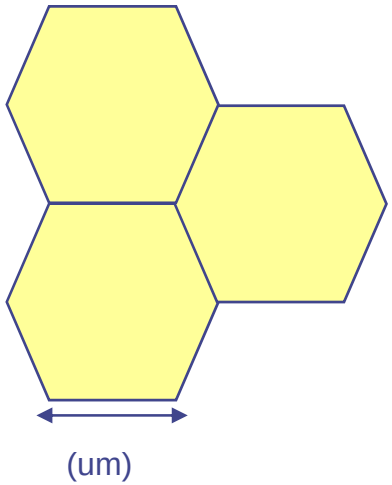
Technical Background

Nanostructured Materials – Grain Size less than 100nm

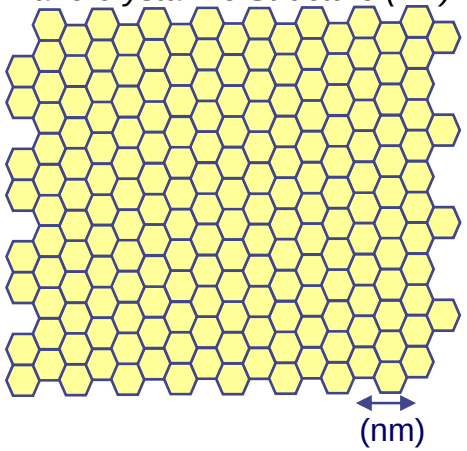
Polycrystalline Structure (um)



nanoPlate - a low-cost, repeatable process for producing nanocrystalline metals and alloys (nano-material)

When grain size is reduced, there is a increase in mechanical properties, due to the Hall-Petch effect

Nano-crystalline Structure (nm)



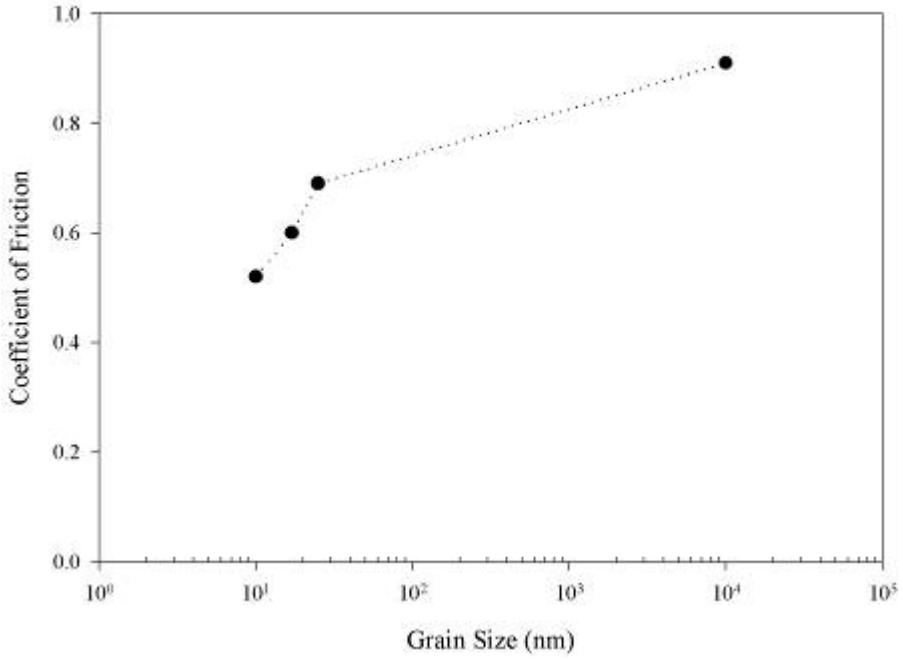
Typical Property Enhancement due to Decreased Grain Size to Nano Regime Includes:

- Hardness (3–5x)
- Yield and Tensile Strength
- Wear Resistance, Impact Resistance

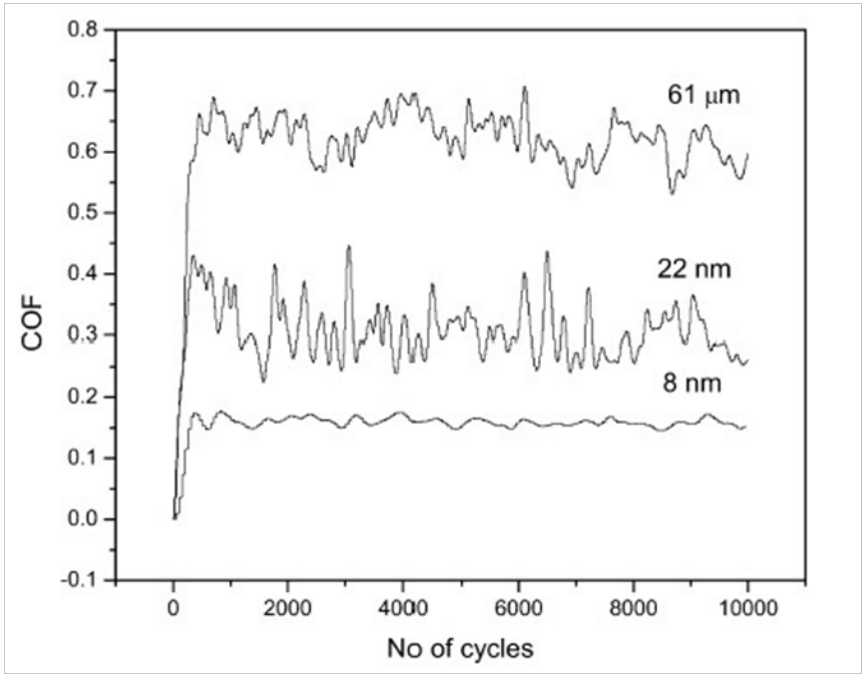
Investigate the relationship between **Microstructure** and **Material Properties for Fastener Applications**

Technical Background

Friction Behavior of Nanostructured Materials



- 6mm Steel ball on Nano Ni Disk
A.M. El-Sherik and U. Erb, in "Nickel-Cobalt 97-Vol. IV, Applications and Materials Performance", F.N. Smith et al. (eds), The Metallurgical Society of CIM, Montreal (1997) 257.

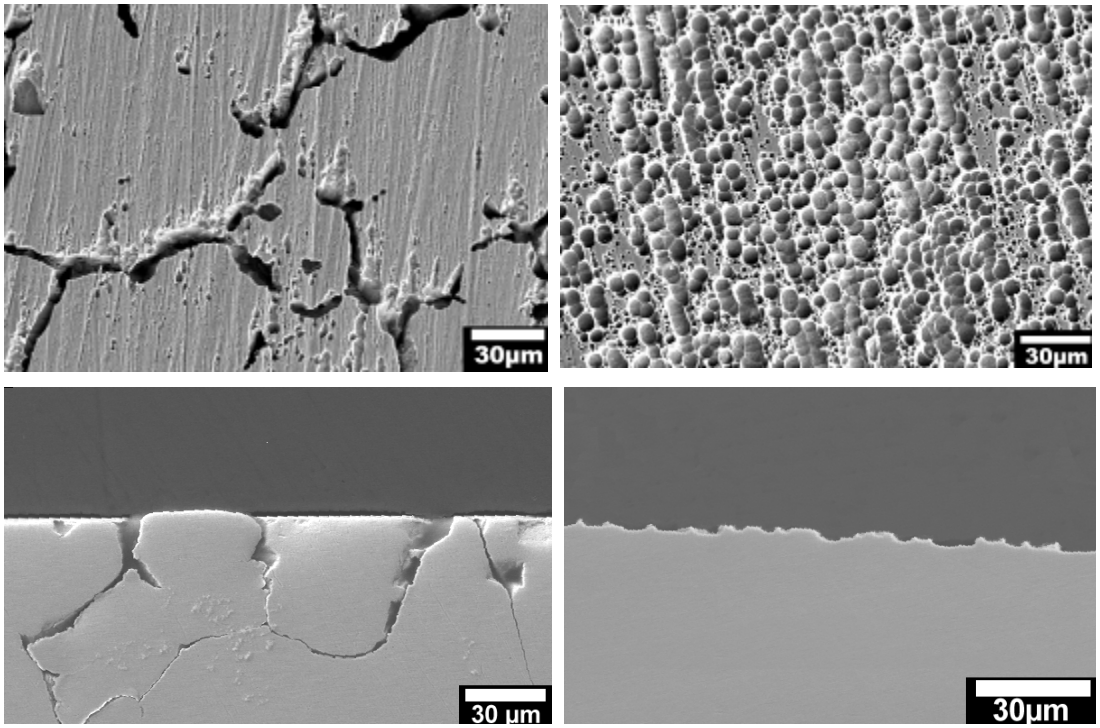


- 8mm Steel ball on Nano Ni disk
R. Mishra, B. Basu, R. Balasubramaniam, Materials Science and Engineering A 373 (2004) p. 370–373

Decrease in grain size has been found to reduce the coefficient of friction

Technical Background

Corrosion Resistance of Nanostructured Nickel



The ultra-fine grain size of nanocrystalline materials reduces the potential for deleterious intergranular corrosion. [Kim et al., AESF Sur/Fin Proc. (2002) 225].

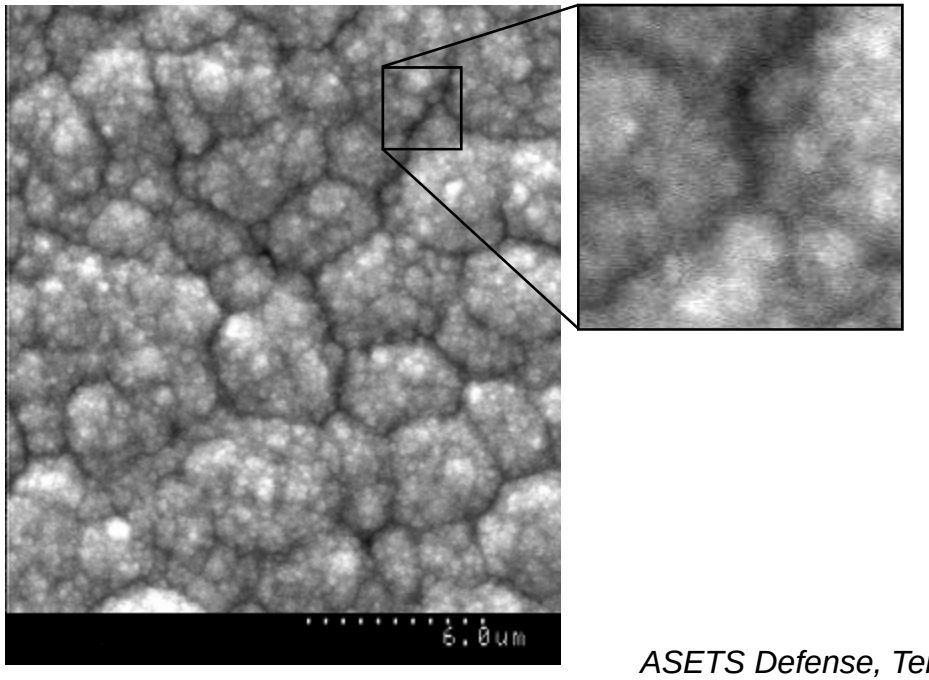
More uniform corrosion, less susceptibility to localized corrosion

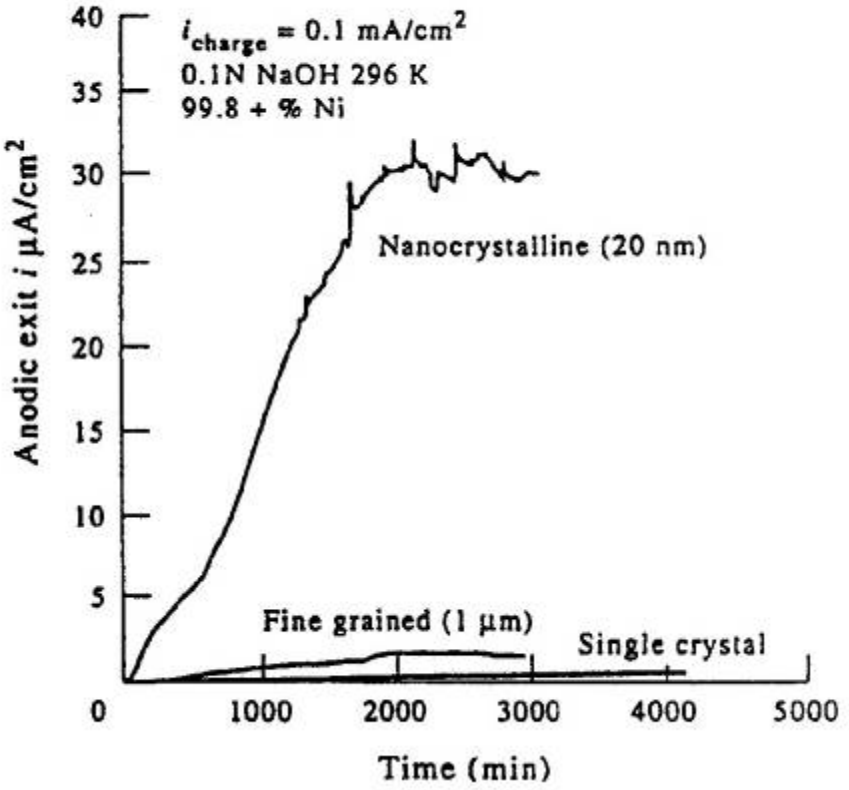
Surface (top) and cross-sectional (bottom) corrosion morphologies of polycrystalline (left) and nanocrystalline (right) Ni tested in de-aerated 0.25M Na_2SO_4.

Technical Background

Hydrogen Permeation through Nanostructured Materials

Increased H_2 permeation through nanocrystalline Zn-alloys will decrease risk of HE issues after baking





Hydrogen permeation transients showing anodic exit current density (flux) vs. time for nanocrystalline (20nm), fine grained (1µm), and single crystal Ni foils [Doyle et al, Acta Metall. Mater, 43 (1995)]

Technical Background

Anticipated Benefits of Nanostructured Zn-Based Coatings

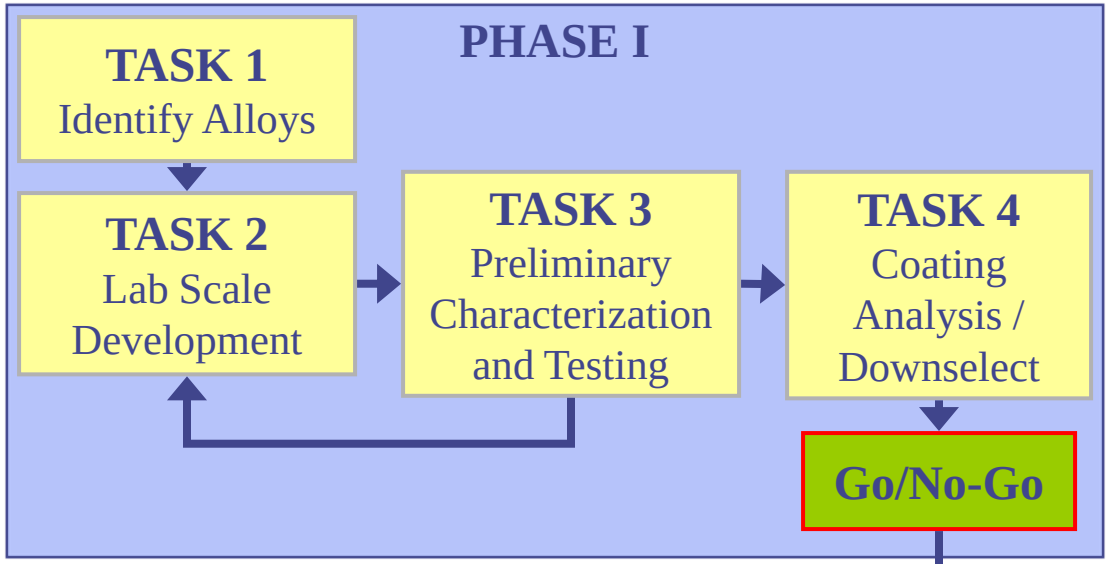
Process

- Versatile production process / Drop-in replacement to Cd
- Pulse plating may be used to vary composition/grain size/phase

Properties/Performance

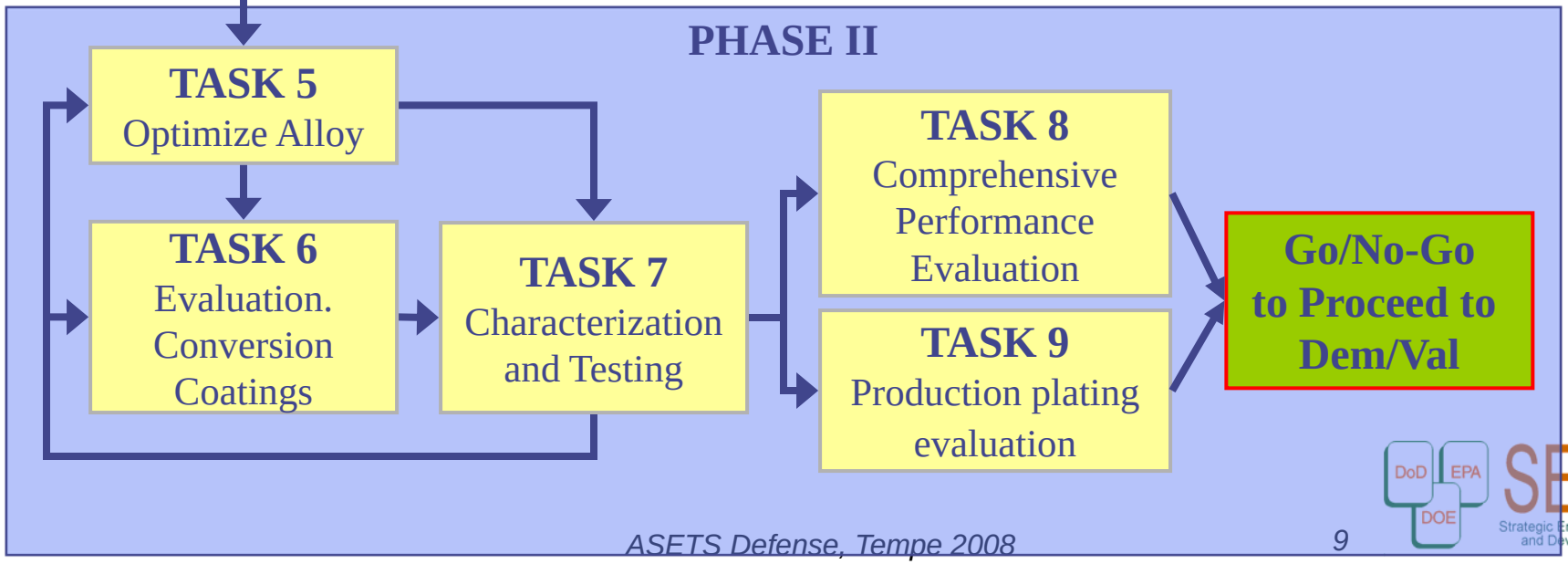
- High hardness, strength and wear/scratch resistance
- High Hydrogen Permeation → Low Hydrogen Embrittlement (non-embrittling, H_2 can be baked-out)
- Fully Dense Uniform / non-localized corrosion
  - → corrosion activity at surface coating surface
  - → good re-embrittlement characteristics
- Low Friction / High lubricity coating

Project Task Flow



TASK 1 – Identification of Nanoscale Coating Alloys
TASK 2 – Laboratory Development of Three Nanoscale Zn-Based Alloys
TASK 3 – Preliminary Characterization and Testing
TASK 4 – Coating Performance Evaluation on HSS
Go/No Go

TASK 5 – Optimization of Specific Nanoscale Alloy
TASK 6 – Evaluation of Conversion Coatings
TASK 7 –Final Characterization and Testing
TASK 8 – Comprehensive Performance Evaluation
TASK 9 – Rack/Tank/Barrel Plating Evaluation
Go/No Go



Technical Approach – Phase I

Laboratory Scale Development and Evaluation Three Nanoscale Zn-Based Coatings

- Specific Zn-alloy constituents TBD (Co, Fe, Ni, Sn, etc)
- Evaluation will include assessment of:
  - Grain size / phase / texture
  - Throwing power, composition/thickness uniformity
  - Adhesion
  - Deposit coherency, ductility
  - Cathodic current efficiency
  - Hydrogen embrittlement potential on high strength steels
  - Corrosion performance (Sacrificial cathodic protection for steel)
  - Density of corrosion product
  - Lubricity/friction characteristics (Torque-tension)→ Match Cd

Recommend Zn-Alloy for further Development and Evaluation in Phase II

Technical Approach - Phase II

Scale-up/Optimization of Selected Nanoscale Zn-Alloy

- **Further optimize Nanoscale deposition process for:**
  - •Deposition on fasteners
  - •Process stability / Industrial Robustness
- **Investigate effective stripping methods**

Evaluation of Cr6+ free Conversion Coatings

Final Characterization and Testing

- Neutral Salt Spray, Fluid corrosion resistance, Torque Tension, Fastener Test Methods (Method 15 Torque Tension), Rotating Beam (RR Moore) Fatigue Tests, Sustained Tensile Load Hydrogen Embrittlement Tests

Rack/Tank/Barrel Plating Evaluation

Completion of Comprehensive Coating Performance Evaluation

- Benchmark comparison against Cd and other competitive technologies

Provide Recommendation to Proceed to Dem/Val

Comments, suggestions, recommendations:

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Questions?